SSERVI-ESF14-060

Author: MEHDI BENNA

ORAL

Exosphere

Variability of Helium, Neon, and Argon in the lunar exosphere as observed by the LADEE NMS instrument

The Neutral Mass Spectrometer (NMS) of the Lunar Atmosphere and Dust Environment Explorer (LADEE) Mission is a high sensitivity quadrupole mass spectrometer designed to measure the composition and variability of the tenuous lunar atmosphere. The exospheric measurements collected by the NMS instrument cover altitudes that ranged from 4 km to 250 km and spanned all local times and selenographic longitudes. Owing to the LADEE orbit design, low altitude measurements were typically collected over the sunrise terminator while high altitude measurements were collected over the sunset terminator.A sizeable fraction of the NMS observing time was dedicated to tracking the spatial and temporal variability of Helium-4, Neon-20 and Argon-40. While the two first species are of solar wind origin the latter is the result of the radiogenic decay of potassium-40. Observations of the Helium-4 confirms its expected day/night asymmetry with a peak density located between the midnight and the sunrise meridians. The asymmetry of Helium is the result of the difference in accommodation temperature between day and night. Global temporal variability of helium-4 of up to factor 5 were also observed. This variability has a very strong correlation with the flux of solar wind alpha particles that were observed by the 2 ARTEMIS spacecraft. Neon-20 exhibits a comparable day/night asymmetry as Helium with a peak density located prior to sunrise. No temporal variability of Neon-20 was detected for the duration of the LADEE mission. Unlike Helium and Neon, the diurnal variation of Argon-40 follows what was already observed by the Apollo 17 mass spectrometer and can be easily associated with adsorption as the surface cools post-sunset and with rapid desorption at sunrise. NMS has also identified an apparent increase of Argon abundance that is localized over the western maria. This Argon “bulge” was not affected by the diurnal motion of the Moon and its spatial extent and amplitude remained constant for the duration of the LADEE mission.

Author: ANTHONY COLAPRETE

ORAL

Exosphere

Initial Results from the LADEE Ultraviolet-Visible Spectrometer

The Lunar Atmosphere and Dust Environment Explorer (LADEE) Ultraviolet Visible Spectrometer (UVS) began commissioning activities in orbit around the moon on October 16, 2013. Science observations began October 23, 2013 and continued until minutes prior to the planned disposal of the LADEE SC on April 18, 2014 (UTC). Over the course of the mission the UVS instrument made a series of systematic observations, including lunar limb stares at both terminators and about local noon, targeted activities, including anti-sun sodium tail observations, north/south limb stares, solar occultations, and instrument calibrations. Initial analysis of these observations have resulted in temporal and spatial mapping of key exosphere species, such as sodium and potassium, and the detection of several other species, for example oxygen, titanium and magnesium. UVS finds that sodium abundance varies with lunar phase, the moons position with respect to Earth's magnetotail and with meteoroid showers. Observations in search of dust, including limb and occultation activities, have provided high signal-to-noise spectra which show variations in extinction and scatter. This talk will summarize initial results from the UVS instrument.

Author: DANA HURLEY
ORAL

Exosphere

Propagation of Water in the Chang'e-3 Exhaust Plume from LADEE Observations

Landing a vehicle on the Moon introduces gases from the exhaust plume into the normally sparse lunar exosphere. A robotic lander such as the Chinese Chang'e-3 lander on the surface of the Moon would require burning an estimated 106 g of rocket fuel over ~12 minutes. This rocket exhaust constitutes a 100 times temporary enhancement to the source rate to the lunar exosphere and an increase in the total mass of 10%. It is important to understand the extent and duration of these effects if operations on the Moon become frequent. Whereas the native lunar exosphere is comprised primarily of helium and argon; the rocket exhaust comprises water, carbon dioxide, ammonia, and other HCNO products. The distribution of particles in the lunar exosphere is largely controlled by the interactions between the particles and the lunar surface. Thus, if the propagation of the exhaust vapors can be monitored, it can reveal previously unknown properties of the gas-surface interaction with the lunar regolith. LADEE was in an elliptical, retrograde orbit with an inclination of 22° about the equator. On the day of the Chang'e-3 landing, the Neutral Mass Spectrometer (NMS) acquired data for two orbits prior to the landing and on 4 of the orbits after the landing. Relevant data were also acquired during one orbit on the day following the landing. On each of these orbits, the NMS is turned on just after passing noon lunar local time and acquires in situ measurements of the neutral density about 2000 km from the landing site. Water is detected at 2 sigma above the background level at this location for the three NMS orbits following the landing. We model the release and propagation of the exhaust gases on the Moon and compare to observations in orbit around the Moon from the Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft. Model results are extremely sensitive to the assumed surface interactions. In particular, because the exhaust gases have such a large initial velocity, the degree to which the molecules thermalize on contact with the regolith modulates the subsequent propagation of exhaust gases. Without full thermalization, the bulk of the exhaust gases will escape the Moon on the first hop off of the lunar surface. We present the comparisons between the models and the observations to constrain the amount of thermalization in the model required to agree with the observations. Therefore, LADEE utilizes volatile constituents released during the Chang'e-3 landing on the Moon to determine surface-exosphere interactions of non-native species to the lunar environment. This opportunistic observation adds to the planned scientific return of the LADEE mission.

SSERVI-ESF14-063

Author: JASON MCLAIN

POSTER

Exosphere

ENAs Backscattering from Lunar Regolith

When solar wind ions interact with the regolith of airless bodies, some fraction neutralizes and backscatters as energetic neutral atoms (ENAs). ENA imagers onboard Chandrayaan and IBEX observed that ~20% of the solar wind protons are reflected as energetic neutral hydrogen atoms. Lab experiments were performed to simulate solar wind conditions to measure the yield and angular distribution of backscattered neutral hydrogen and helium from Apollo 17 breccia dust. Time-of-Flight analysis was performed to resolve the ENA kinetic energy distribution to model the complex multi-scattering processes involved in the neutralization and subsequent reflection from various surfaces.

Author: ANDREW POPPE
POSTER

Exosphere

Martian planetary heavy ion sputtering of Phobos and Deimos: implications for the production of neutral tori

The Martian moons, Phobos and Deimos, have long been suspected to be the sources of tenuous neutral gas and dust tori encircling Mars. The neutral tori, first suggested in order to explain observations of interplanetary magnetic field perturbations by the Phobos-2 spacecraft near the orbit of Phobos, have been attributed to many sources, including direct outgassing from Phobos, micrometeoroid impact vaporization, and charged particle sputtering. While direct outgassing has been ruled out based on later measurements, micrometeoroid impact vaporization and charged particle sputtering must operate at some level based on observations at other airless bodies. Previous models have addressed charged particle sputtering of Phobos by the solar wind; however, Phobos and Deimos are also subject to a significant, if temporally variable, flux of heavy planetary ions escaping from Mars, including O^+, O_2^+, and CO_2^+. In this report, we use a combination MHD / test-particle model to calculate the flux of planetary heavy ions to Phobos and in turn, calculate the neutral sputtered flux due to these heavy ions. We show that depending on the solar cycle, the solar wind conditions, and Phobos' location, heavy-ion sputtering of Phobos can generate neutral fluxes up to ten times that from solar wind sputtering. Under such conditions, heavy ion sputtering may be the dominant source of neutrals in the Phobos torus. We discuss implications for the neutral tori and suggest that the MAVEN spacecraft may be able to detect these tori via pick-up ions once in orbit around Mars.

Author: ANDREW POPPE
ORAL

Exosphere

LADEE/LDEX Observations of Pick-up Ion Variability in the Lunar Exosphere

The lunar neutral exosphere is generated by a variety of sources, including thermal and photon-stimulated desorption, micrometeoroid impact vaporization, and charged particle sputtering. The relative importance of each of these production mechanisms should vary by species, location, and external conditions; however, definitive measurements have only been made for some production mechanisms for specific species. The Lunar Dust EXperiment onboard the LADEE mission was designed to investigate the micron and sub-micron sized dust environment around the Moon. Additionally, the instrument has also recorded extensive signatures of the total pick-up ion current around the Moon, originating from photo-ionization and charge exchange ionization of the lunar neutral exosphere. We have compared these measurements to a model of lunar pick-up ion fluxes from the exosphere that includes the presence of neutral species generated by thermal desorption, photon-stimulated desorption, sputtering, and impact vaporization. We present trends identified in the data and discuss implications for our understanding of the lunar exosphere as well as exospheres around other airless bodies throughout the solar system.

Author: KURT RETHERFORD

Exosphere

ORAL

Lunar Volatile Transport in the Exosphere and from Impact Plumes: LRO/LAMP Observing Campaigns Coordinated with LADEE

The Lyman Alpha Mapping Project (LAMP) is an ultraviolet (UV) spectrograph on the Lunar Reconnaissance Orbiter (LRO) that maps the lunar albedo and investigates the lunar exosphere at far-UV wavelengths. Lunar helium atmospheric emissions have been detected remotely with LAMP (Stern et al. 2012), enabling global investigations of its distribution and variability. Helium studies show the abundance varies with solar wind conditions (as expected), including stoppages of helium in-flux during Earth magnetotail transits (Feldman et al. 2012) and a few interesting cases of rapid helium abundance increases (Cook & Stern 2014). LCROSS impact plume observations with LAMP detected H2, CO, Hg, Mg, and Ca (Gladstone et al. 2010), which together with LCROSS observations revealed a much richer mix of volatiles trapped within the PSRs than previously anticipated. GRAIL spacecraft impact plume observations with LAMP detected H and Hg at a high latitude sunlit region (Retherford et al., LPSC, 2013). LAMP's lightcurves of the time evolution of these emissions provide useful constraints to detailed gas plume dynamics models for such impacts reported by Hurley et al. 2012. Tentative detections of argon gas just nightward of the dusk terminator (Cook et al., LPSC, 2014) have a latitudinal distribution that agrees well with model simulations (Grava et al., submitted to Icarus, 2014). Molecular hydrogen is also detected with LAMP (Stern et al. 2013). New, more constraining upper limits to 27 other potential atmosphere constituents have been determined using LAMP (Cook et al. 2013). Lunar Atmospheric and Dust Environment (LADEE) Neutral Mass Spectrometer instrument measures in situ He, Ar, and Ne (Benna et al., LPSC, 2014). The LADEE Ultraviolet-Visible Spectrometer (UVS) routinely measures Na and K emissions, and additionally searches for exospheric dust signatures (Colaprete et al., LPSC, 2014). LAMP searches for similar exospheric dust signatures from dust scattered sunlight and found that upper limits for lunar horizon glow during these observations were at least two orders of magnitude smaller than that inferred from coronal photographs taken during the Apollo 15 mission (Feldman et al. 2014). LADEE's Lunar Dust Experiment (LDEX) occasionally observes bursts of dust particles that are seemingly related to individual meteoroid impacts, but like LAMP, has not detected persistent clouds of fine-grained exospheric dust (Horanyi et al., LPSC, 2014). Analysis of LAMP observations obtained during a series of campaigns coordinated with the LADEE mission is currently underway, and we will present our latest findings. LAMP's view of twilight local time regions from LRO's polar orbit, when combined with LADEE's low (<22.5° N/S) latitude retrograde orbit and instrument set, provides a new global perspective on the lunar exosphere that promises to improve our understanding of volatile and dust transport processes.

Author: KURT RETHERFORD

ORAL

Exosphere

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SSERVI-ESF14-068

Author: MENELAOS SARANTOS

ORAL

Exosphere

The Na and K content of the Moon's exosphere is limited by the impact vaporization rate

On the basis of scale height considerations, the Na exosphere of the Moon is believed to be provided mainly by photon-stimulated desorption (PSD). Recent measurements of Na ions from the Kaguya ion spectrometer demonstrated that the sodium atmosphere exhibits a dawn-dusk asymmetry and does not peak at the subsolar point as expected from a photon source acting on an unlimited reservoir. These measurements implied that the reservoir for exospheric Na is rapidly depleted on the dayside and must be replenished on the nightside by exospheric migration and/or micrometeoroid impacts. In this view of the exosphere-surface system, impacts vaporize sodium from the subsoil, and the recycled portion of the gas ejecta can be reintroduced to the exosphere by PSD, which acts only on the topmost Angstrom of a grain. Monte Carlo transport simulations of the finite reservoir of Na on the surface performed here demonstrate that the range of impact vaporization rates in the literature suffice to provide the observed exosphere (~70 Na cm-3 near the subsolar point). Besides this proof of concept, three new results are suggested by these simulations. One, the dependence of exospheric sodium with latitude derived from ground based telescopes and Kaguya can be explained by this scheme only if the impact vapor is concentrated at the equator and drops off rapidly at higher latitudes. Two, the location of the peak, 10 degrees off the subsolar point as inferred from Kaguya data, constrains the PSD yield. Third, for a species like K that clearly has a non-uniform distribution on the lunar surface, the simulations demonstrate that if impact vaporization limits the PSD rate, the resulting exosphere will exhibit a periodic variation within each lunation. Therefore, it is possible to probe with Kaguya and LADEE measurements the unknown distribution of Na in the lunar subsoil.

SSERVI-ESF14-069

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ORAL

Exosphere

Constraining refractory elements of the Moon's exosphere from LADEE measurements

We updated our previously published model of transport of refractories in the lunar exosphere (e.g, Mg, Ti, Fe) to infer source and loss mechanisms for these species. New features of this model include: 1) the incorporation of inhomogeneities in surface composition for these elements using Lunar Prospector maps; and 2) the adoption of sputtering maps that describe the exclusion of the solar wind from certain portions of the lunar surface because of magnetic anomalies. Using these maps and a Monte Carlo particle model we simulated the expected variation of these exospheric elements with lunar phase subject to different assumptions for the local time dependence of incident micrometeoroids. Limits to the production by micrometeoroid impacts and sputtering can be obtained by comparing these simulations with the brightness of exospheric emission lines measured by Ultraviolet Spectrometer (UVS) on the Lunar Atmosphere and Dust Experiment Explorer (LADEE).

Author: TIMOTHY STUBBS

ORAL

Exosphere

The Effects of Meteoroid Streams on the Lunar Environment: Observations from the LADEE Mission

Impacts on the lunar surface from meteoroid streams encountered by the Earth-Moon system can result in measurable enhancements in both the lunar atmosphere and dust environment. Here we describe the annual meteoroid streams incident at the Moon during the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission, and discuss their effects on the lunar environment. The LADEE science payload consisted of three instruments: the Ultraviolet/Visible Spectrometer (UVS); the Lunar Dust Experiment (LDEX); and the Neutral Mass Spectrometer (NMS). All three instruments were capable of detecting the effects of an encounter with a meteoroid stream.The Earth-Moon system frequently encounters debris trails from comets and asteroids, which are referred to as meteoroid streams. The meteoroids in these streams have similar velocities and are on near-parallel trajectories, so when they enter the Earth's atmosphere the resulting shower of meteors appears to be emanating from a virtual point on the sky called the radiant. Meteor (and meteoroid) rates vary as a function of the Earth's position in its orbit, with an activity curve that increases to a peak and then decreases. During its time in lunar orbit, the LADEE mission coincided with 18 out of 35 IAU established annual streams. These streams are relatively well characterized and are broad enough that both the Earth and Moon pass through them. Unlike at the Earth, all of the stream meteoroids incident at the Moon will impact its surface and create ejecta clouds and release neutral and ionized species into the exosphere. As stream meteoroids move on near-parallel trajectories we expect to observe asymmetries in their effects on the lunar environment. Therefore, it is necessary to know where the streams are normally incident on the lunar surface (i.e., the locations of the stream radiants in the Moon frame).Based on the Zenith Hourly Rates (ZHR) derived from meteors observed at Earth, one might expect the Geminids (ZHR peak ≈92–120 on 13/14 December 2013) and Quadrantids (ZHR peak of ≈120 or greater on 3 January 2014) to have had the most significant effect on the lunar environment during the mission. (For comparison, the hourly rate for sporadic background meteors is ≈9.5.) While a substantial exospheric response was clearly observed by the LADEE instruments during the Geminids, the apparent response during the Quadrantids was more subdued. One contribution to this difference may have been due to the location of the stream radiant on the lunar surface relative to LADEE's orbit. The Geminids radiant was predicted to be at Selenocentric Solar Ecliptic (SSE) latitude of 10.2°N, which was very close to LADEE's equatorial orbit. Whereas the Quadrantids radiant was much farther poleward of LADEE at SSE latitude of 64.8°N, which could explain the diminished exospheric activity and suggests that the response of the lunar environment to meteoroid streams could be relatively localized.

Author: DIANE WOODEN

Exosphere

ORAL

LADEE UVS Observations of Solar Occultation: Exospheric Dust along lines-of-sight above the Dawn Terminator

Introduction: The Lunar Atmosphere and Dust Environment Explorer (LADEE) is a lunar orbiter launched in September 2012 that investigates the composition and temporal variation of the tenuous lunar exosphere and dust environment. A primary science goal of the LADEE mission is to characterize the dust lunar exosphere prior to future lunar exploration activities, which may alter the lunar environment. To address this goal, the LADEE instrument suite includes an Ultraviolet/ Visible Spectrometer (UVS) that has two sets of optics: a limb-viewing telescope, and a solar viewing telescope. The solar viewer foreoptics has six sequential baffles followed by a diffuser that allows UVS to stare directly at the solar disk as the Sun starts to set (or rise from) behind the lunar limb. Solar viewer measurements have very high signal to noise (SNR>500) for 10–26 ms integration times. The 1-degree solar viewer field of view subtends a diameter of ~8 km and samples a column of 400-450 km over the dawn terminator.Occultation Measurements: Solar occultation observations are captured at the lunar sunrise limb, as the LADEE spacecraft passes into the lunar nightside, facing the sun (the spacecraft orbit is near-equatorial retrograde). Spectral collection begins when the solar viewer field of view grazing point is ~40 km above the lunar surface. UVS then continues to collect spectra with the solar viewer pointed directly at the sun, sampling progressively lower altitudes. Sampling continues as the solar disk is partially and then totally occulted by the lunar limb. For this work, UVS occultation measurements for solar viewer fields of view grazing altitudes spanning ~30 – 0 km above the terrain, are analyzed for the signatures of extinction by lunar exospheric dust. Results: For our analyses, the ratio of two spectra (Io and I) defines a time-dependent optical depth. For each occultation activity, Io comes from solar viewer measurements at time in the activity when the limb-viewing telescope is pointed downwards at unlit terrain, corresponding to the dark side of the terminator and solar longitudes of more than about 272 deg. This configuration minimizes scatter from the lunar surface into the telescope foreoptic while the solar viewer foreoptic stares directly at the sun. Spectrum I comes from solar viewer measurements at later times in the activity, down to ~0 km grazing point altitude. A spectral ratio (I/Io) between these two time points (and, correspondingly, field of view altitudes) is then examined to search for dust signatures, which would manifest as differences in spectral absorption from extinction and/or scattering. Our results indicate wavelength-dependent extinction as a function of altitude. We attribute the detected spectral color changes to the presence of sub-micron sized dust grains in the lunar exosphere within specific altitude ranges. We will present and compare our results to previous models[1,2] of the lunar dust exosphere.